## 2.1 Non-Invasive Determination and Monitoring of Free-Phase Dense Nonaqueous Phase Liquids (DNAPLS) by Seismic Reflection Techniques

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### Abstract

Current technology for the evaluation and remediation of contaminated soil and groundwater is inadequate to meet mandated cleanup levels in a cost-effective and environmentally acceptable manner. More must be learned before realistic cleanup strategies can be developed. The technology gap comes from incomplete knowledge about the subsurface geohydrology within which various remediation technologies are applied and the inability to adequately characterize movement of pollutants. The path of contaminant movement is complex because of the interaction between earth materials and contaminants that may represent the subsurface.

Determination of the location and distribution of subsurface dense nonaqueous phase liquid (DNAPL) contamination poses specific challenges. Because DNAPLs are denser than groundwater the migration of these fluids in the subsurface is controlled in part by gravity such that the direction of contaminant flow is not necessarily the same as groundwater flow. Below the water table DNAPLs tend to accumulate in highly concentrated discrete layers or pools in structural lows or Asinks@ above low permeability geologic layers. Furthermore, the occurrence of DNAPL in the subsurface can be highly localized and can occur at differing structural levels. Therefore, determination of the distribution of the contamination can be difficult because of missed pools of highly concentrated product. The key to maximizing the amount of DNAPL recovered from the subsurface is constructing a comprehensive and detailed picture of the geometry and spatial variations of the lithologic units comprising the subsurface. In addition, direct detection of DNAPL itself by non-invasive techniques will immensely aid remediation efforts.

Traditional methods used to determine location and extent of DNAPL contamination require point-source data obtained from invasive methods such as borehole geophysical logs and cone penetrometer data. These invasive methods not only run the risk of cross-contamination of an aquifer, but also may not locate pools of contamination because of inadequate spatial coverage.

The seismic reflection method provides a non-invasive means to acquire spatially dense subsurface information. Typically, a two-dimensional high-resolution seismic reflection survey may have data points only a foot apart. A three-dimensional seismic reflection survey, because of the greater cost involved, may have data points every 5 feet throughout a regular grid. Vertical resolution of a typical high-resolution seismic reflection survey is three to five feet. These data, combined with existing borehole information, can provide a detailed picture of the subsurface.

In addition to providing a detailed structural picture of the subsurface, seismic data if properly calibrated with borehole information, can be used to map typical aquifer properties such as porosity, permeability, and clay content. This information is integrated into two and three dimensional structural models to delineate preferential pathways for subsurface contaminant transport. Furthermore, under certain circumstances, borehole calibrated seismic reflection data can be used to infer the presence of a specific fluid within a lithologic unit. These techniques utilize the fact that a change in the fluid content within a lithologic unit causes change in the recorded seismic amplitude as a function of the angle of incidence of the impinging energy, i.e. the source to receiver offset distance. In the Petroleum industry these reflection amplitude-versus-offset (AVO) techniques have been used successfully for over ten years to directly detect the presence of subsurface hydrocarbons (Ostrander, 1984; Allen and Peddy, 1993). Recently, we have used this method to delineate free-phase DNAPL concentrations at a depth of 150 feet at the Savannah River Site (Waddell et al., 1997).

The research has been conducted at the following DOE sites where DNAPL contamination is known to be present: Savannah River Site, SC and Hanford Site, WA and a DOD site, the Charleston Naval Weapons Station, SC. In working at these different sites the project team has developed a methodology that can be used to investigate other sites,

a) Evaluation of existing geological and geophysical data for the amount and distribution of DNAPL,
b) Seismic modeling to determine whether or not an AVO anomaly would be expected from DNAPL saturated sediments,
c) Acquisition and processing of seismic data designed to image the DNAPL.

In summary, seismic reflection surveying and seismic reflection AVO analysis are noninvasive techniques that, under certain circumstances, provide a means of (1) mapping subsurface lows where DNAPL might accumulate, and 2) to directly detect the presence of free- phase DNAPL in the subsurface. This approach significantly reduces the cost of site characterization and prevents cross-contamination between aquifers by reducing the number of monitoring wells.

The seismic reflection survey is the only subsurface remote sensing method capable of providing dense spatial sampling of subsurface material properties at depths 15 feet and greater. In addition, emerging technology, such as application of the AVO techniques described and proposed herein, present the possibility of directly detecting the presence of subsurface DNAPL. These technologies will result is a significantly more extensive understanding of the subsurface characteristics and properties of waste sites, which will lead to an efficient and cost-effective cleanup of groundwater.

Furthermore DNAPLs can be identified more quickly by seismic reflection surveying because of the dense subsurface sampling and direct detection potential. This information will provide a better basis for developing groundwater models used to design remediation strategies. The delineation of contaminant plumes and the placement of monitoring wells will be facilitated, thereby saving time and money over a method using the random installation of wells.

Application of seismic reflection techniques to subsurface site characterization will reduce public and occupational health risks because, as a non-invasive technique, there will be less exposure to hazardous subsurface contaminants. Field crews will assume less risk. There is less disturbance of aquifers and fewer opportunities for inadvertently spreading contaminants.

Site remediation is always negotiable and site-specific. The more defensible the characterization information, the better the chance to obtain regulatory approval.

The geophysical techniques proposed are well established in the petroleum industry where they have been applied in an extensive range of geological settings. It remains to implement the technology in the hydrogeological and subsurface contamination remediation industries.